Microelectronics Reliability Considerations for Extreme Environments

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OUTLINE

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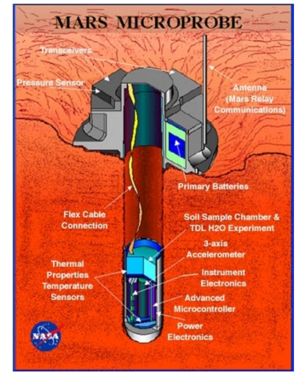
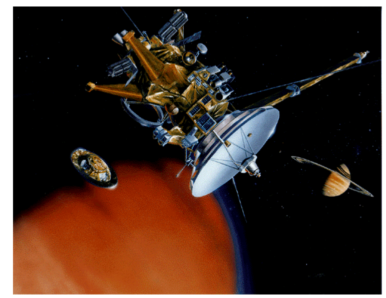
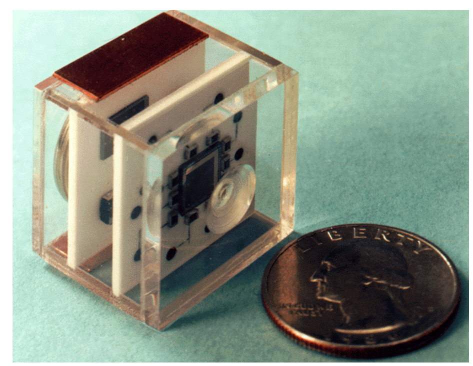
INTRODUCTION

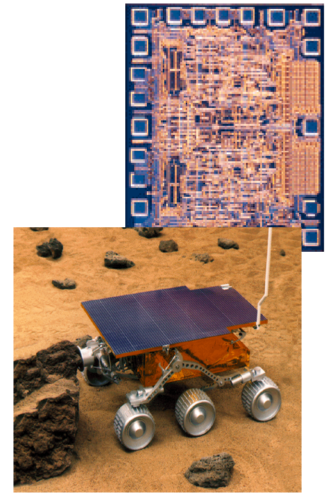
- Space system applications require the Use of commercially developed electronic components in critical applications and increasingly in extreme environments
- Devices from simple transistors to complex “System-on- a-Chip” are applied throughout the design
- The Space market represents too small a customer to drive commercial technology development toward greater reliability
- Understanding the capabilities of the technologies of interest and their related failure mechanisms is essential to the Realization of These Systems





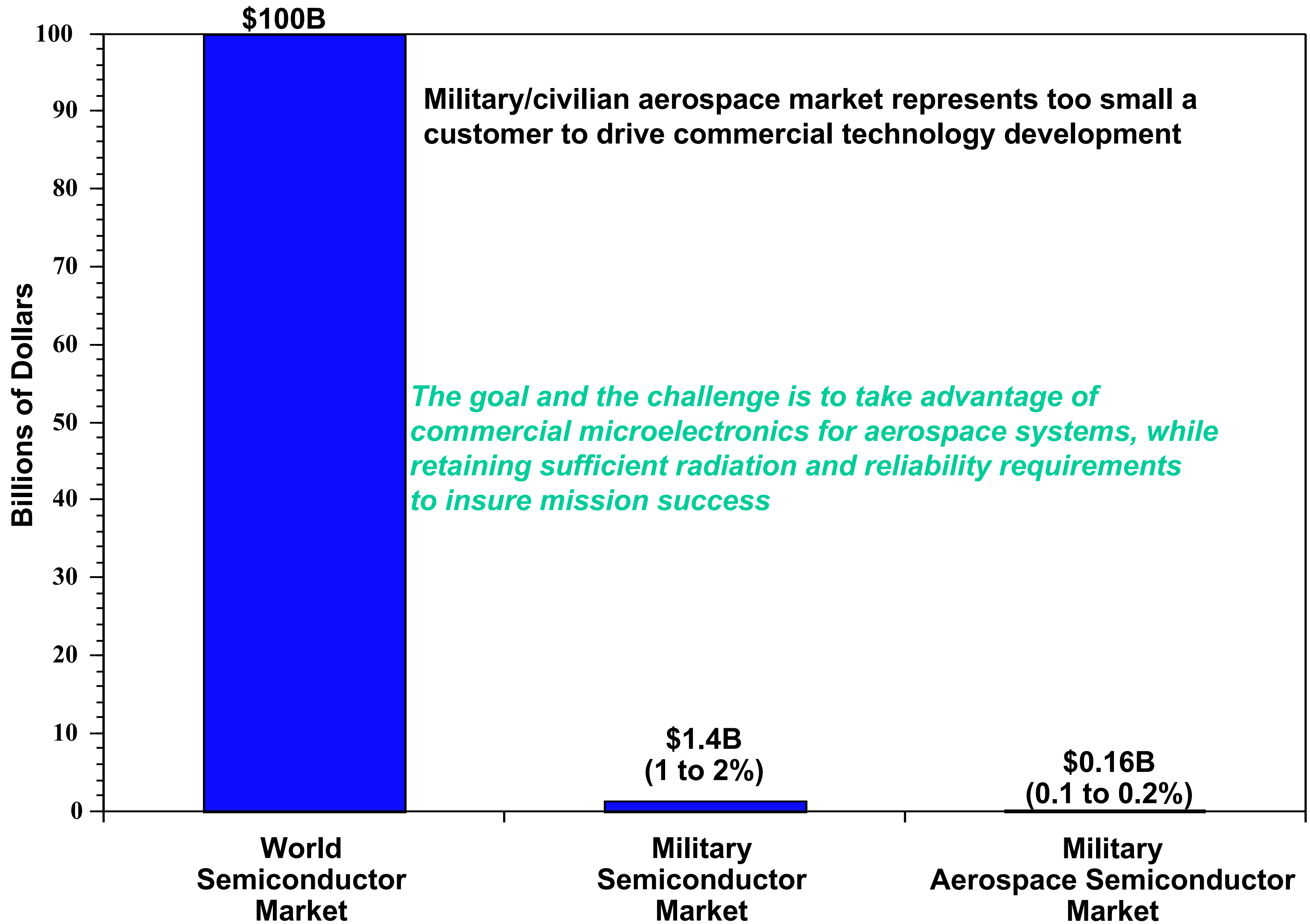


CHALLENGES FOR EXTREME ENVIRONMENTS



- **Environmental Challenges**
  - Extreme Temperatures
  - Radiation Effects and Environments
  - Corrosive Environments
  - Thermal Cycling
- **Technical Challenges**
  - Application of devices beyond the range of design
  - Reduction in Mass, Volume and available power
  - Stability of Design over the environmental range
- **Procurement Challenges**
  - Diminishing Availability of Radiation Tolerant Processes
  - The commercial industry does not face this problem
  - Small Volume Procurements are not Desirable

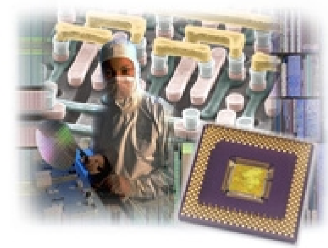
1996 World Semiconductor Business

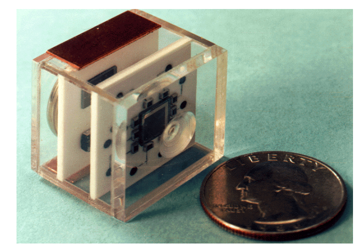


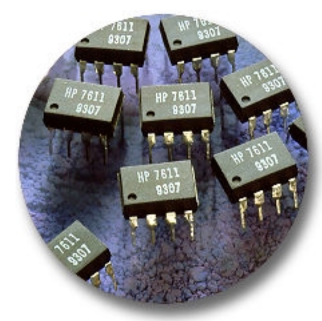
ELECTRONIC PARTS PROJECT

PROJECT OBJECTIVES

- Evaluate and Assess New and Advanced Microelectronics Device Technologies for Application in High Reliability Aerospace Systems
  - Identify Common Failure Modes and Mechanisms and Develop Methods for Risk Mitigation
  - Perform Reliability Evaluation and Characterization of New and Emerging Microelectronics Device Technologies
  - Provide an Infusion Path for Application of New Microelectronics Technology in NASA Systems
  - Provide NASA Projects with Microelectronics Technology Selection, Application, and Validation Guidelines
  - Develop Innovative Reliability and Qualification Methods







ELECTRONIC PARTS PROJECT OBJECTIVES AND TECHNICAL AREAS

Project Objective

Evaluate and Assess New and Advanced Microelectronics Device Technologies for Application in High Reliability Systems

Major Thrusts

- Identify Common Failure Modes and Mechanisms of New Technologies
- Evaluation and Characterization of New Device Technologies
- Provide an Infusion Path for Advanced technologies
- Develop innovative Reliability and Qualification Methods

Areas of Emphasis

- **MEMS Reliability and Characterization**
  - Reliability Evaluation
  - Microgyro
  - Accelerometer
  - Magnetometer
- **Device Evaluation and Characterization**
  - ADC, DSP, DC/DC
  - Memories, FPGA
  - APS, µprocessors
- **Microwave Devices and Technologies**
  - GaAs Devices
  - MPM & MTWTA
  - RF Switches
  - HF Devices
- **Electronics for Extreme Environments**
  - Low Temp. Elect
  - High Temp. Elect
  - SiC, GaN
- **Optoelectronic and Photonic Technologies**
  - Semiconductor Lasers
  - LED, Detectors
  - High Bandgap Devices
  - QWIPs
- **Reliability Evaluation & Qualification Techniques**
  - SOI, Cu-Metalization
  - PEM, Memory Modules
  - KGD, CL Imaging
  - ASIC Foundries

ELECTRONICS FOR EXTREME ENVIRONMENTS

Current Activities

- Survey of material properties and device characteristics at low temperatures
- Study of low temperature effects on semiconductor devices
- Characterization tests of selected devices over the -120 to +40 C temperature range
- Formation of a consortium to address reliability issues of electronics in extreme environments and leverage available resources

RELIABILITY CONSIDERATIONS FOR EXTREME TEMPERATURE ELECTRONICS

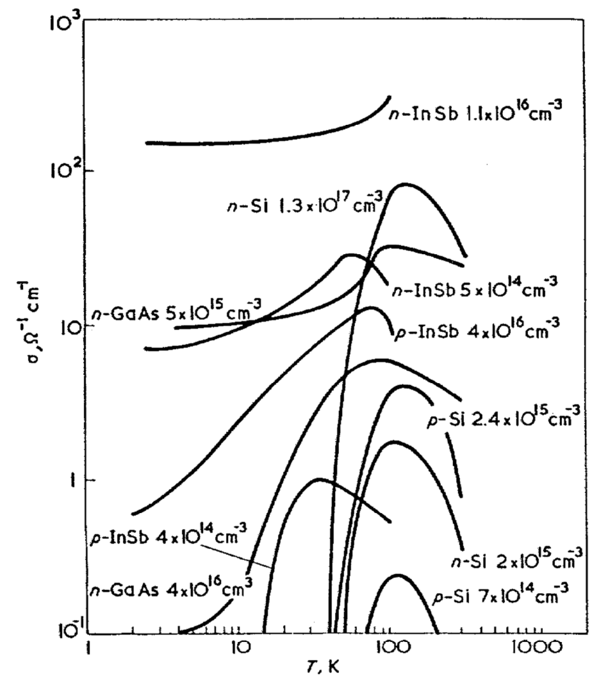
Low Temperature Effects

- **Semiconductor Device Reliability**
  - Characterization
  - Life Test
  - Reliability Investigation
- **Radiation Characterization**
  - Total Ionizing Dose
  - Single Event Effects
- **Material Issues**
  - Selection
  - Characterization
  - Thermal Characteristics
- **Packaging Issues**
  - Die Attach
  - Temp Cycling
  - Pkg Attach
- **Operation and Performance**
  - Design vs. Performance
  - Characterization

RELIABILITY CONSIDERATIONS

Semiconductor Device Reliability

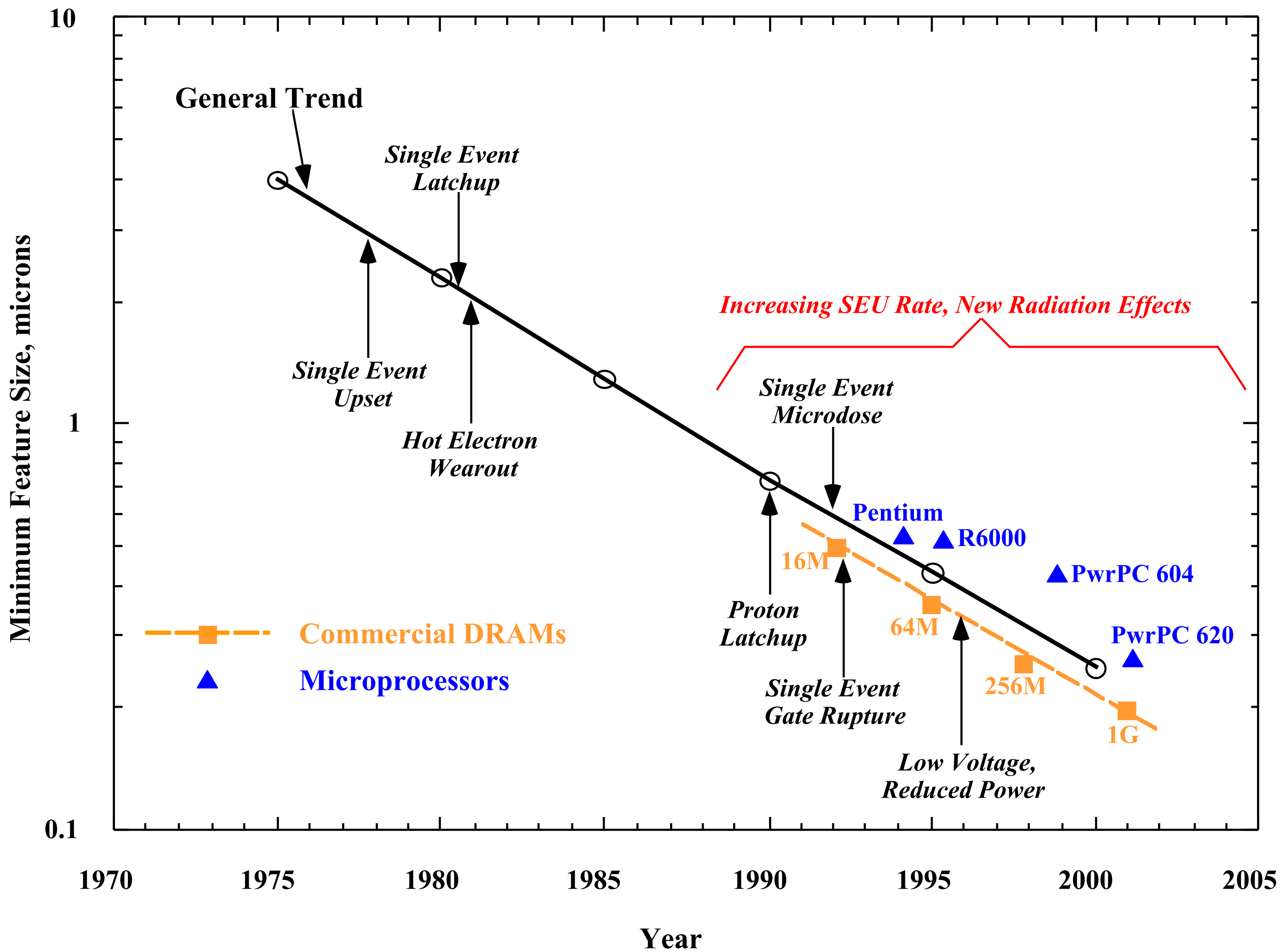
- Conductivity and carrier mobility are greatly affected by temperature variations
- Operation in the range of 150k to 290k has been shown, However little characterization data is available over this range.
- Reliability Issues to consider
  - Changes in Threshold Voltage
  - Short Channel Effects
  - Hot Carrier Degradation
  - Carrier Freeze-out (Si at lower temperatures)



RADIATION EFFECTS ON MICROELECTRONICS

Type of Radiation Effect	Effect on Devices
Total Ionizing Dose (TID) – protons, electrons, gamma rays	Both gradual, parametric degradation and sudden functional failure – cumulative effect
– Enhanced low dose rate effect	– Severe RHA problem in linear bipolar devices
Single Event Effects (SEE) – protons, heavy ions	Variety of single particle effects
– Single Event Upset (SEU)	– Soft failures – change in logic state
– Single Event Latchup (SEL)	– Functional and catastrophic failure
– Single Event Functionality Interrupt (SEFI)	– Recoverable functional failure; change in operating mode
– Single Event Burnout (SEB) and Gate Rupture (SEGR)	– Catastrophic failure in power transistors
– Single Event Dielectric Rupture (SEDR)	– "Hard" SEUs; similar to SEGR, FPGA anti-fuse shorting
Displacement damage effects – protons, neutrons	Bulk lattice damage – "billiard ball" collisions – Analog devices, solar cells, optocouplers
Single particle "microdose" – heavy ions	TID failure of a single transistor – "weak" bits
Single particle-induced transients in linear/analog parts	Large transient that can upset following digital circuits

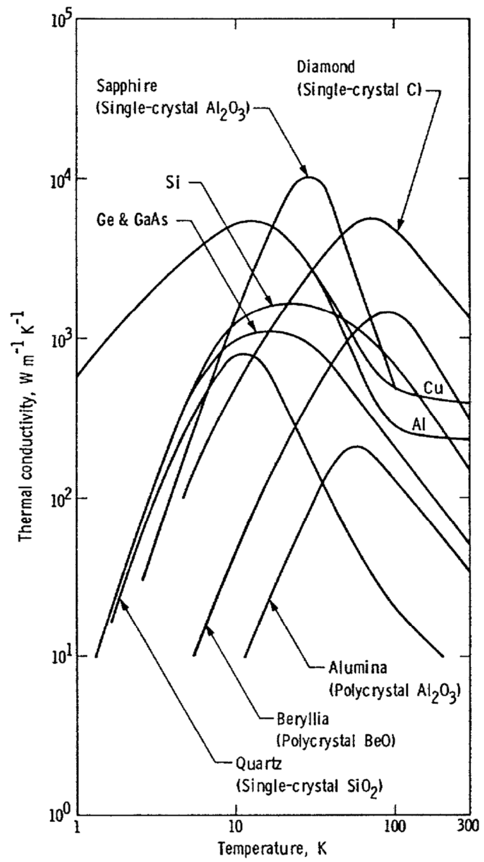
RADIATION EFFECTS TRENDS IN MICROELECTRONICS



RELIABILITY CONSIDERATIONS

Material Properties

- Selection of materials to minimize CTE mismatch
- Characterization of materials over the temperature range of interest.
- Consideration of Thermal Conductivity as a function of temperature
- Stability of contact materials



RELIABILITY CONSIDERATIONS

Packaging Issues

- Stress and strain of die and package attach are affected by:
  - Size of the area to be joined
  - Differences in CTE between joined materials
  - Temperature range
- Most available temperature cycling data relates to a limited temperature range (-55 to +125 °C) and a limited number of cycles
- The effects of prolonged thermal cycling must be addressed

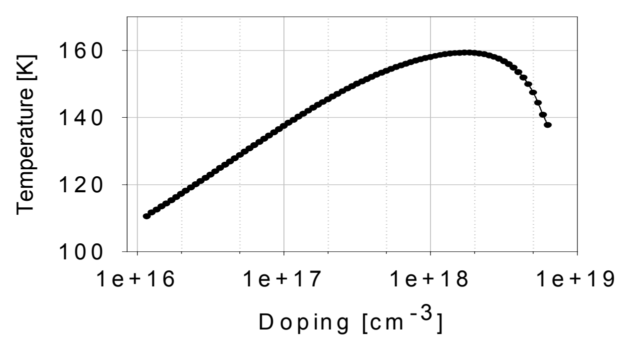
FUTURE ACTIVITIES

Electronics for Extreme Environments

- **Area Objectives**
- Assess Reliability Effects of Electronic Parts Used Under Low/High Temperature Conditions
- Identify Failure Modes and Mechanisms Affecting Electronic Parts Under Extreme Environments
- Characterize Capabilities of Commercial Devices and Processes to Operate Under Extreme Environmental Conditions
- Investigate New and Advanced Device Technologies for Application in Extreme Environments

- **Proposed Tasks**
- Low Temperature Effects on Device Reliability
- High Temperature Electronics
- Reliability of SiC Devices
- GaN Technology Evaluation
- Characterization of Passive Electronic Parts at Cryogenic Temperatures

Calculated Freeze-Out of As-Doped Si



SUMMARY AND CONCLUSIONS

- Operation of electronic components in extreme environments represents a major challenge to designers and reliability engineers
- Electronic components have been shown to operate at LN temperatures under static conditions. However, long term reliability concerns exist especially under temperature cycling conditions
- Synergistic effects between various environmental components (temperature, radiation) must be taken into account
- The Electronics for Extreme Environments Consortium will provide significant leverage of available resources and capabilities to address this challenge.